AIAA Space 2011 Conference

Kennedy Space Center Orion Processing Team Planning for Ground Operations

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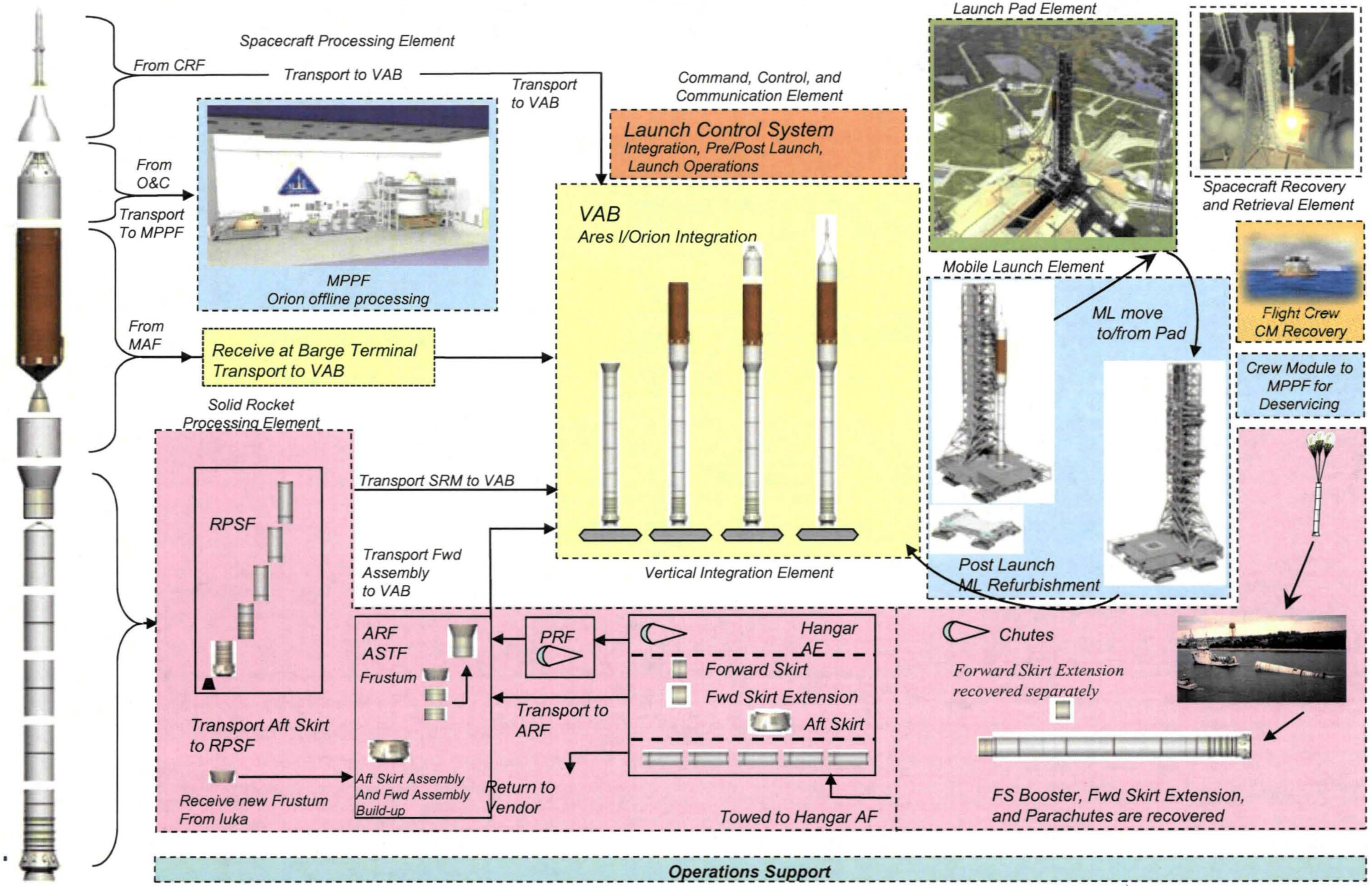
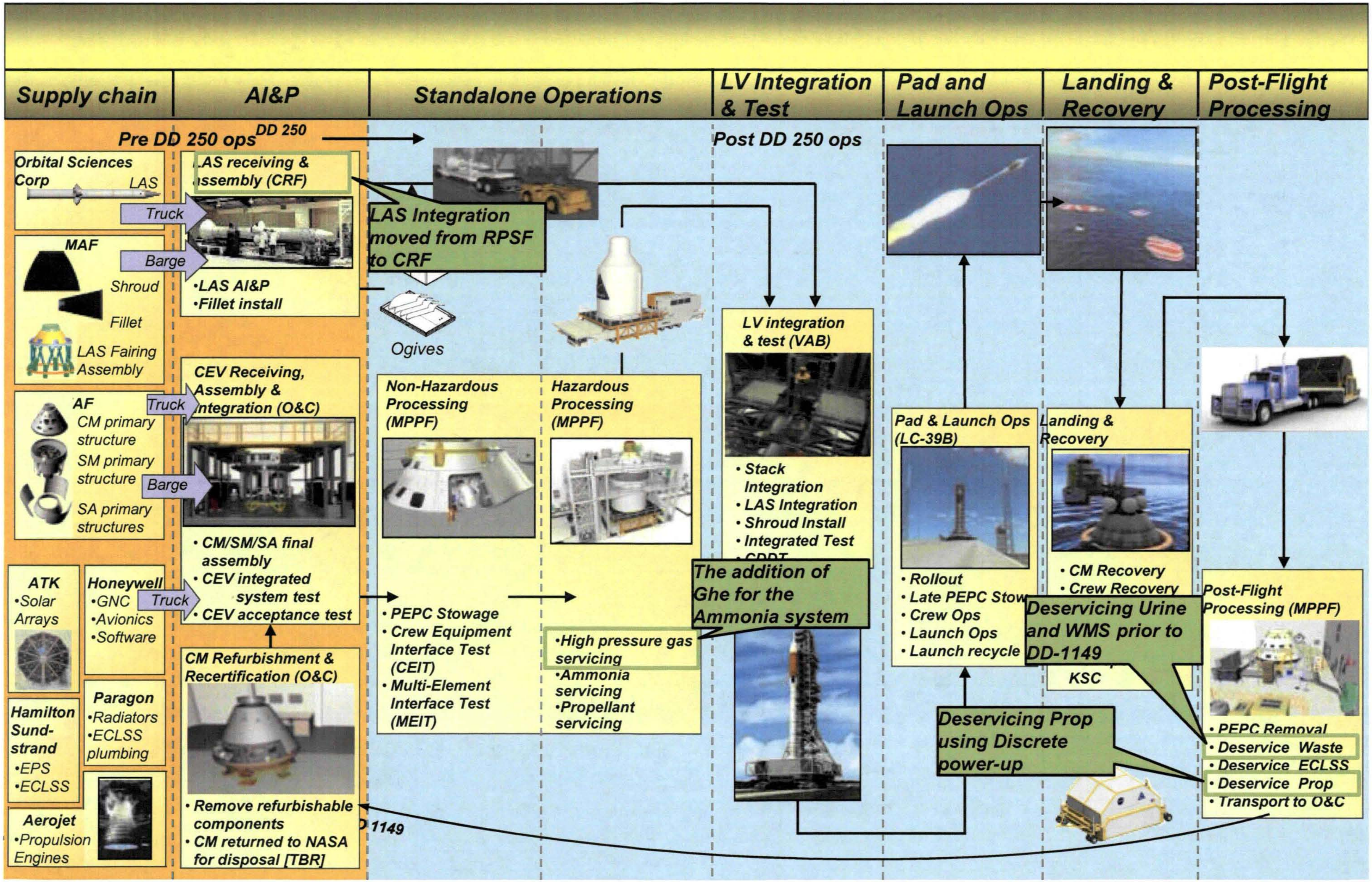
Outline

- **Constellation Ares I/Orion/Ground Ops Elements**
- **Orion Ground Operations Flow**
- **Orion Operations Planning Process and Toolset Overview**
  - Orion Concept of Operations by Phase
  - Ops Analysis Capabilities Overview
  - Operations Planning Evolution
  - Functional Flow Block Diagrams
  - Operations Timeline Development
  - Discrete Event Simulation (DES) Modeling
  - Ground Operations Planning Document Database (GOPDb)
- **Using Operations Planning Tools for Operability Improvements**
  - Kaizen/Lean Events
  - Mockups
  - Human Factors Analysis

Constellation Ares I/Orion/Ground Operations Elements



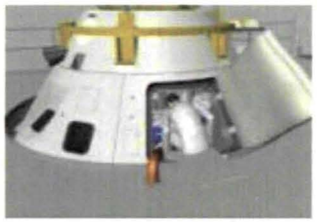
Orion Ground Operations Flow



MPPF – Non-Hazardous Ops

From O&C

MPPF



Initial Provisions Stowage

-T-0 connection (power, control, data, purge)

-Time critical PEPC fit checks

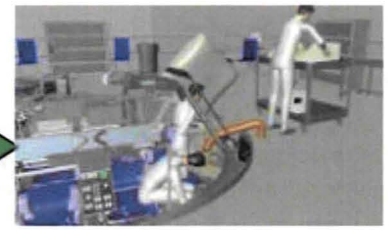
Crew Equipment Interface Testing - CEIT

-Verify flight crew to Orion interfaces

Multi Element Interface Test - MEIT

-Verify Orion interfaces to other flight elements (ISS, Altair, etc.)

-Not for every flow



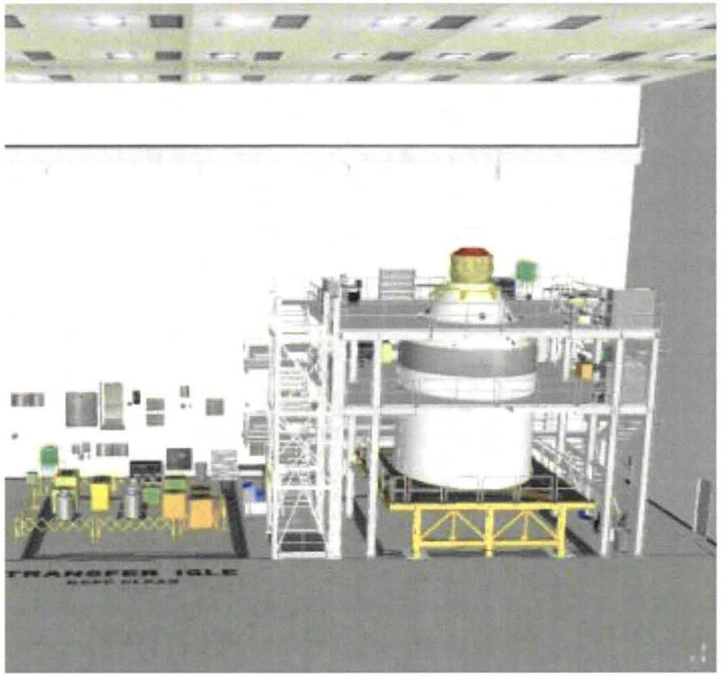
Cargo Stowage and Integration

-PEPC stowage

-Potable water service and sample

MPPF – Hazardous Ops

MPPF



To VAB

High Pressure Gas Servicing

-GO2, GN2, GHe,

Ammonia Servicing

-NH3

Hypergolic Servicing

-N2O4, MMH, N2H4

VAB - Launch Vehicle Integration Ops

Short Stack & LAS to VAB

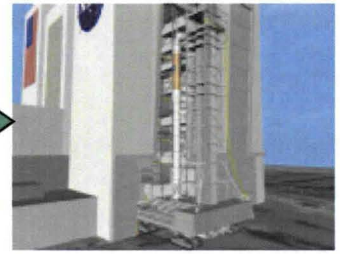
- *Short Stack vertical transport from the MPPF*
- *LAS Horizontal transport from the CRF*

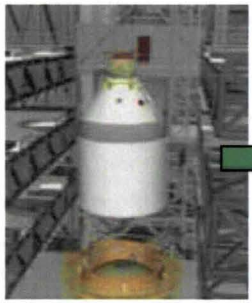
From MPPF

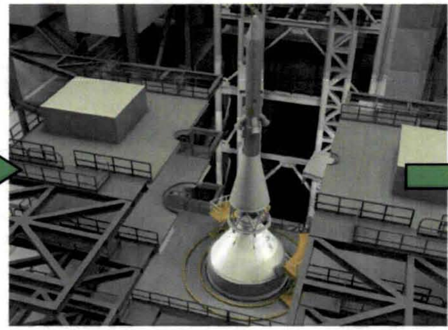
from CRF

VAB

Rollout to Pad







Lift & Mate Short Stack to CLV

- *Lift and mechanical mate with the upper stage IU*
- *Electrical mates*
- *Connect T-0*
- *Initiate Purge*
- *Perform I/F test (powered)*

LAS Integration to CM

- *Lift and mechanical mate LAS to CM*
- *LAS to CM Electrical mate*
- *LAS Interface Test & S&A rotation test (powered)*
- *Ordnance mate*

Ogive Installation

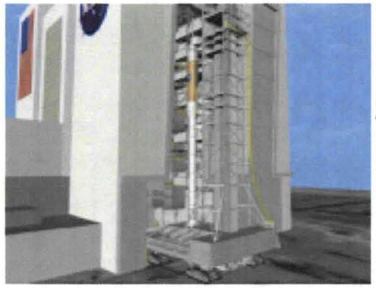
- *Install Ogive Panels (4)*
- *Closeout TPS*
- *Establish internal access (white room)*

Integrated Testing

- *Vehicle power up & health status*
- *IVT (including RF testing)*
- *Potable water sample*
- *Countdown Demo Test (CDDT)*

Pad and Launch Ops

-Rollout to Pad with active purge
-Connect Pad to ML interfaces
-Establish External access (CAA & SM VAA)

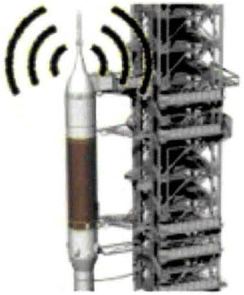


Rollout

From VAB

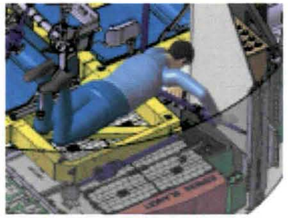
LC-39B

Mission Ops



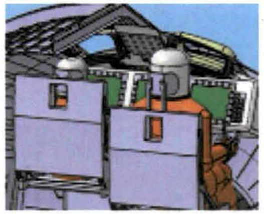
Communications Testing

-Orion Power-up
-Pad IVT
-Comm. End-to-End Testing
  ▪ Uses antennas on LAS



Late Stowage and Final Ordnance

- Late PEPC Stowage
- CM, SM Ordnance Ops
- LAS arm inhibit removals (S&A pins)



Crew Operations

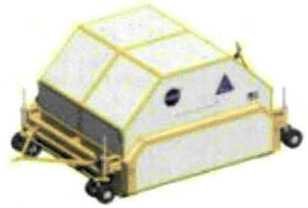
-Crew Ingress
-Hatch Seal Leak Checks
-Cabin Leak Checks
-White Room seal retract
-CAA retract

Launch Readiness Through T-0

- Final countdown and Launch

Landing & Recovery Ops

From Flight Ops



To MPPF

Water Landing

-Location data transmitted to MCC, relayed to recovery crew
-Auto-safing of pyros & fluid systems performed and status provided to MCC
-CM beacon transmits vehicle location to recovery crew

Water Recovery

-Remove CM from water (crew on-board)
-Crew egress after CM secured on ship
-Manual Pyro Safing
-Remove Time Critical PEPC

Transportation

-Install lifting device on CM
-Transfer CM to transporter on dock
-Prepare for over-the-road transportation
  - Transfer CM transporter to trailer
-Transported to MPPF at KSC

Post Flight De-servicing

From Landing Site

MPPF

O&C

De-service Preps

- *Remove CM transporter from over the road trailer*
- *Clean CM & transporter*
- *Move CM transporter in MPPF airlock*
- *Move CM & transporter into High bay for de-servicing*

Remove PEPC

- *Remove seats*
- *Remove non-time critical PEPC*
- *Remove Human Waste*
- *Flush and Drain Urine system and decontaminate WMS*

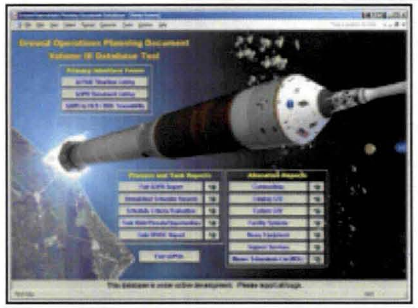
De-servicing

- *Data Retrieval if required*
- *De-service Ammonia system*
- *De-service ECLSS gases*
- *Discrete Propulsion system Power-up*
- *Decontaminate Hydrazine system*

Return to O&C

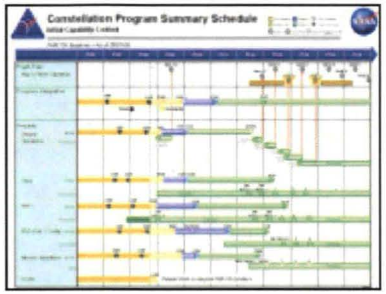
- *Move from de-servicing area*
- *Configure for Transport*
- *Transport CM and components back to O&C*

Operations Analysis Capabilities



Ground Operations Planning Database

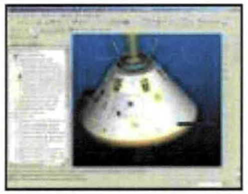
Provides a common, authoritative data repository for operations definition.



Schedule/Manifest Planning

Utilized for integration of flight vehicles, facilities, flight/ground constraints and resource needs into an overall integrated processing site schedule and a launch manifest.

Pro E



Catia

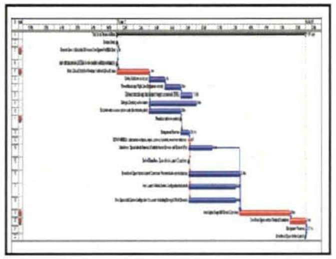
Delmia

Process Visualization

Models operations/systems design interaction in a "virtual reality environment"

Provides the ability to influence the design process to make systems more operable

- VAB platform interference
- Orion single Ogive concept
- Access arm height on ML
- ML cameras location

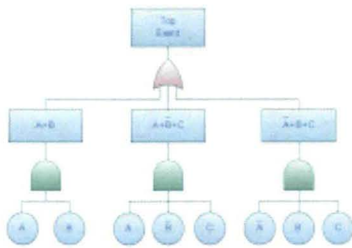


Integrated Timeline

Utilized to plan the ops processing flow and monitor compliance with critical path requirements.

Reliability, Maintainability, Availability

Determines the ability of design systems to perform required function in terms of operations, functional configuration, and ability to recover from failures.



Discrete Event Simulation

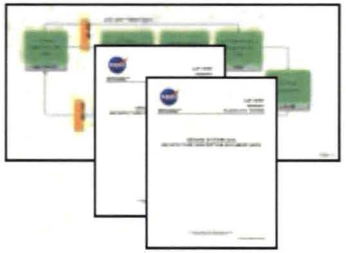
Utilized to develop a conceptual framework that represents the operation of a system and perform analyses on the behavior.

- Flight Rate Achievability
- GOP Architecture Needs
- Launch separation Viability

Operations Planning Evolution

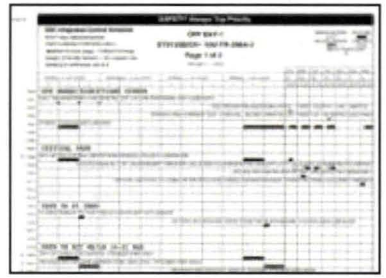
Program Formulation — **IOC**

Process Definition



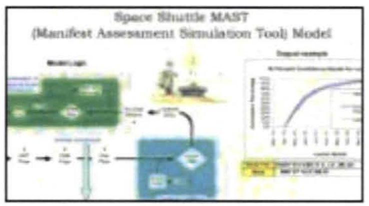
High level operational concepts and functional flows

Task level operational concepts, detailed FFBDs, off nominal task/event definition

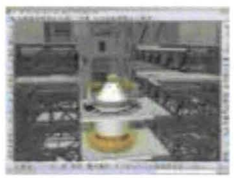


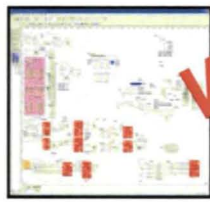
Operations requirements, procedures, Launch Commit Criteria, detailed mission schedules

Analysis Tools



Conceptual models, deterministic timelines, historical comparisons





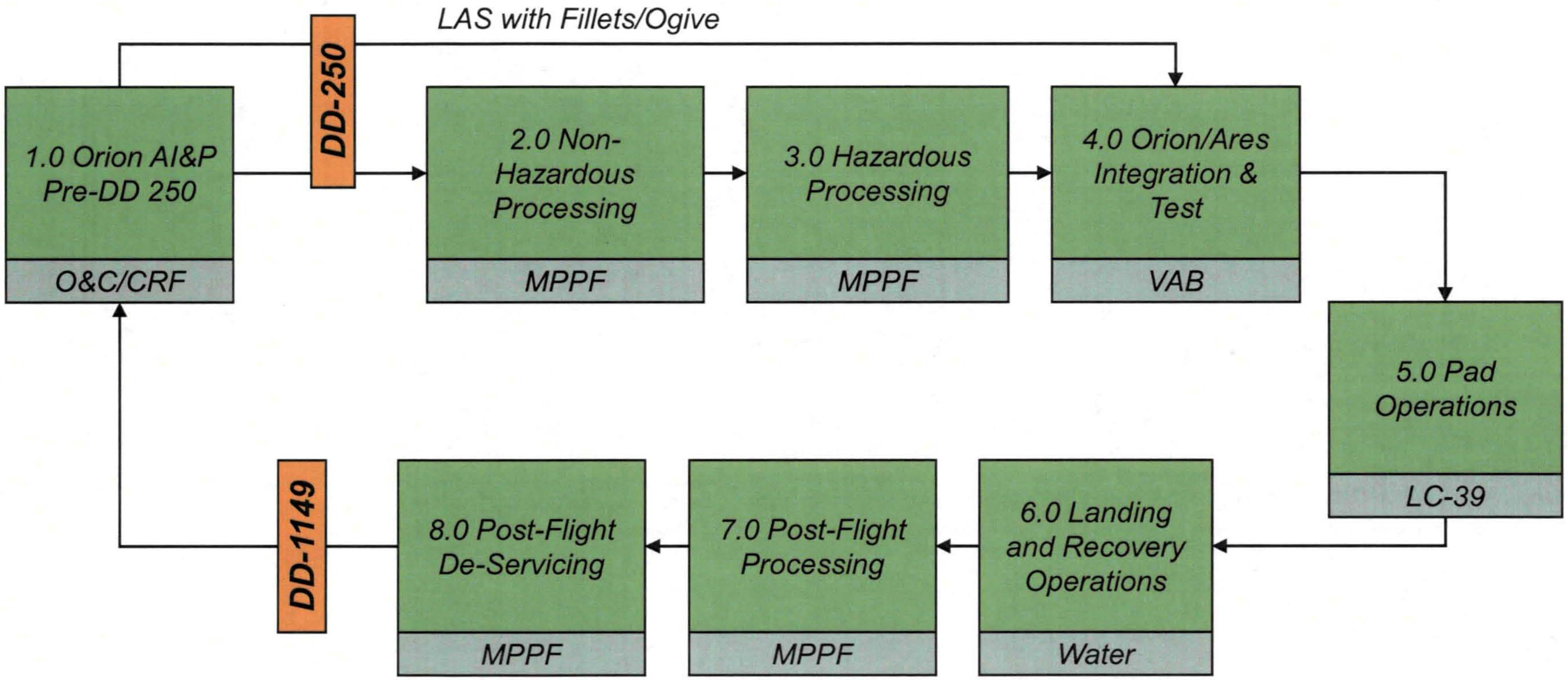
Subsystem/task level modeling, design-informed probabilistic simulations

Watch Items Database

Certified requirements verification models, ops contractor/gov't partnered manifest assessments

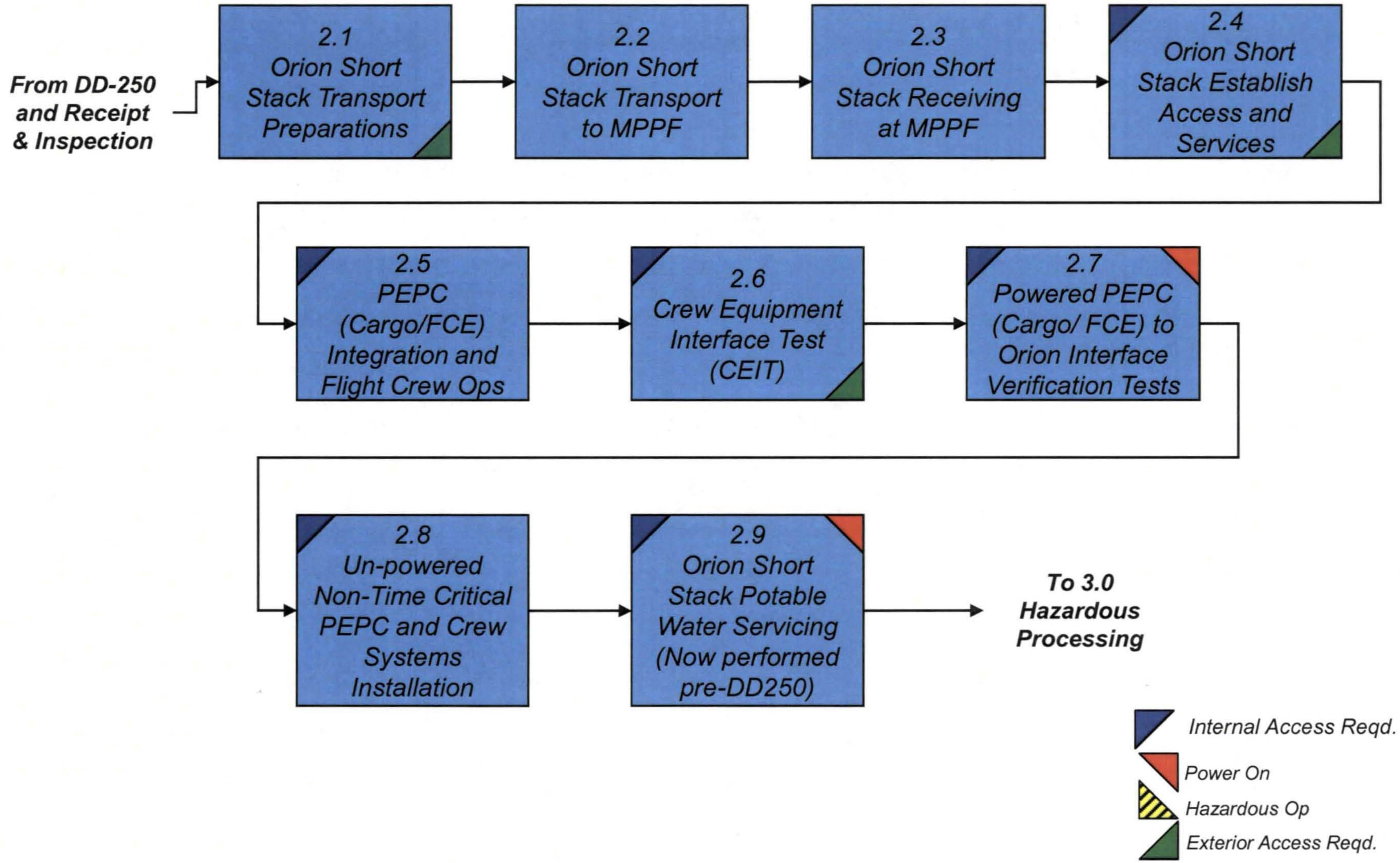
Operations definition parallels design evolution. Primary objective is to optimize the "operations design" in conjunction with the flight and ground systems design.

Orion 606D Ground Ops Functional Flow Tier 1



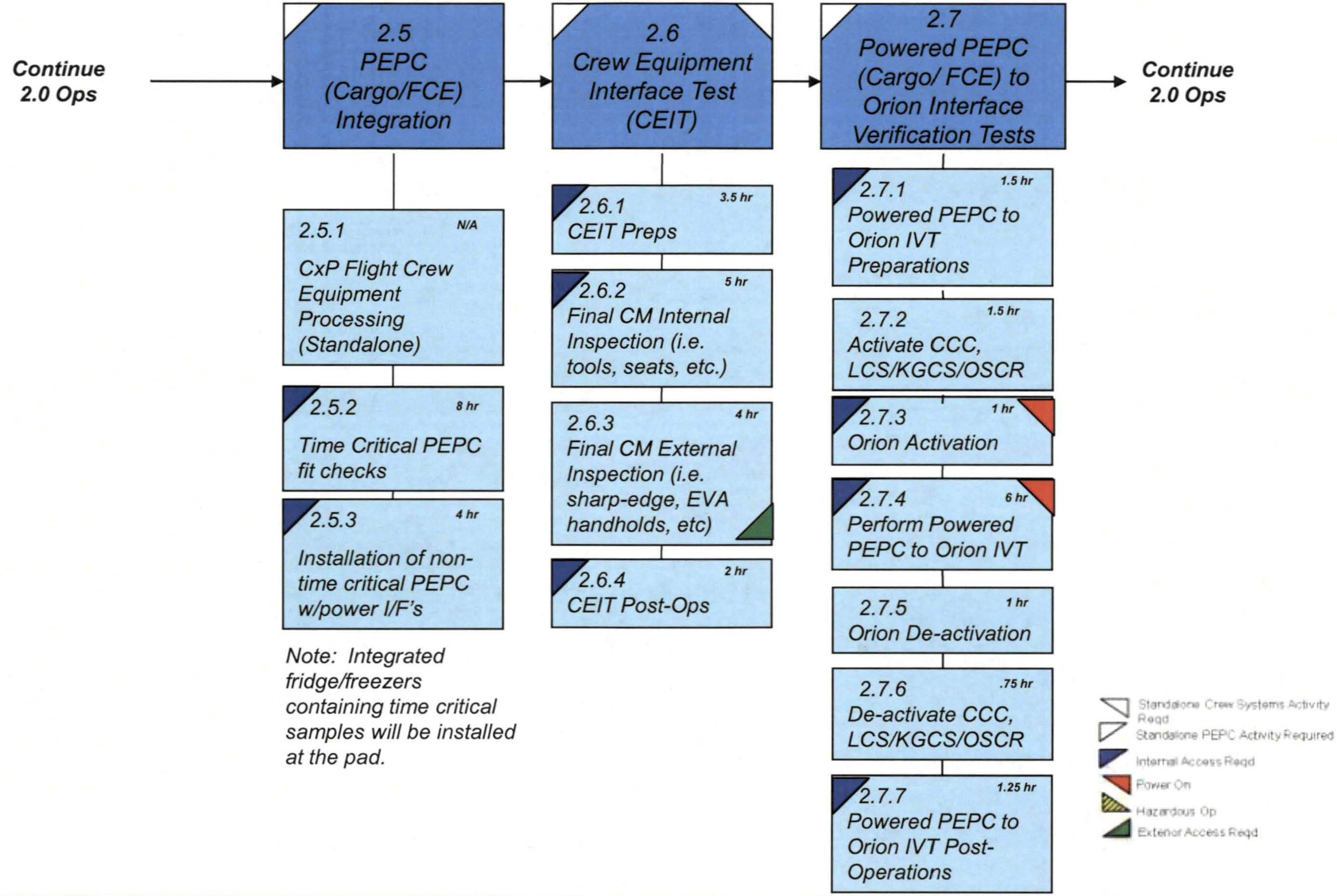
Orion 606D Ground Ops Functional Flow

2.0 Non-Hazardous Processing - Tier 2



Orion 606D Ground Ops Functional Flow

2.0 Non-Hazardous Processing- Tier 3



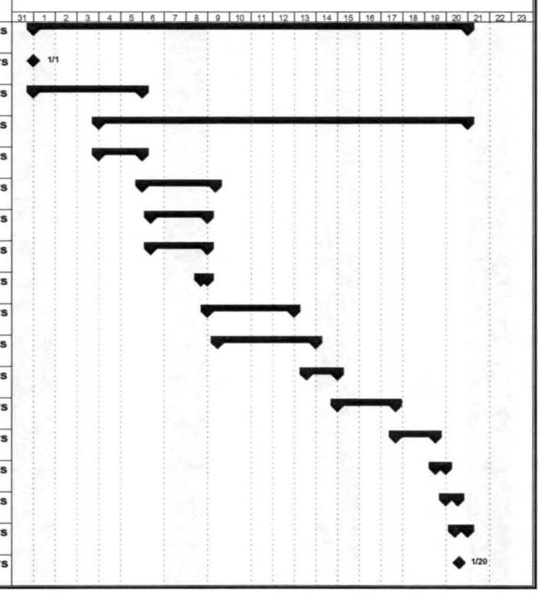
Operations Timeline Development

- Subsystems level ground processing expertise from Shuttle and ISS used to estimate timeline durations and resource loading
- Delphi method used to develop durations based on multiple experts per subsystem
- Timeline inputs used to develop preliminary schedules, based on learning curve, work shifting and special testing

- Examples:
  - Integrated operations and hazardous operations at the MPPF are based on five days/three shifts; remaining offline operations are based on five days/two shifts
  - Learning curve factors gradually decrease for subsequent flights, based on ISS, Shuttle and Apollo historical data
  - No learning curve considered after 3rd flight

Orion Hazardous Servicing Example Timeline

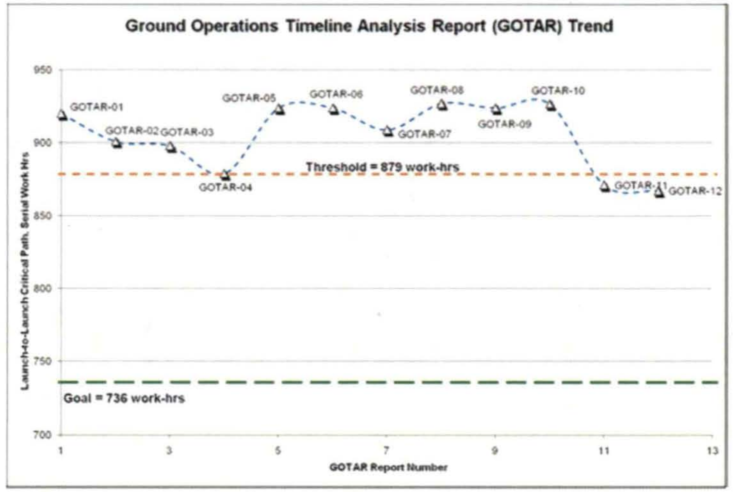
GOPD Section #	Task Name	Most Likely
4.2	Orion Short Stack Offline Ground Processing	469.4 hrs
4.2.1	DD250 of Orion Short Stack to NASA	0 hrs
4.2.2	Orion Non-Hazardous Processing	111 hrs
4.2.3	Orion Short Stack Hazardous Servicing Operations	408.65 hrs
4.2.3.1	Setup for High Pressure Gas Servicing (GO2, GN2, GHe)	58.25 hrs
4.2.3.2	CM/SM Flight Pressure GO2 Servicing	73.9 hrs
4.2.3.3	CM/SM Flight Pressure GN2 Servicing	61.4 hrs
4.2.3.4	CM/SM Flight Pressure GHe Servicing	58.15 hrs
4.2.3.5	High Pressure Gas Servicing Post-Ops	1.75 hrs
4.2.3.6	Orion Short Stack (CM/SM/SA) Potable Water Sample and Configure for Hyper and NH3 Servicing	97 hrs
4.2.3.7	CM NH3 Ammonia Servicing	106.25 hrs
4.2.3.8	SM N2O4 Oxidizer Servicing	41.75 hrs
4.2.3.9	CM N2H4 Propellant Servicing	57 hrs
4.2.3.10	SM MMH Fuel Servicing	44 hrs
4.2.3.11	De-Configure Orion Short Stack Post-Servicing	11.25 hrs
4.2.3.12	Orion Short Stack (CM/SM/SA) Transport Preparations	13.75 hrs
4.2.3.13	Orion Short Stack (CM/SM/SA) Transport to VAB	11.5 hrs
	Orion Short Stack in VAB Transfer Aisle	0 hrs

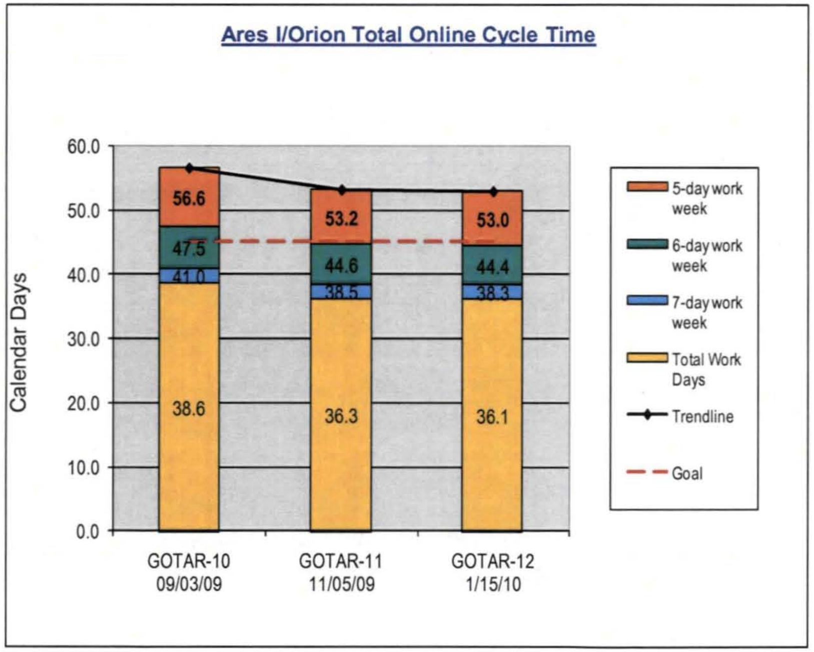


Ground Operations Timeline Analysis Report (GOTAR)

◆ Purpose

- Assess the progress made by the Ares/Orion/GO Projects towards meeting the CARD's critical path requirements.
  - ➢ [CA6002-PO] The Constellation Architecture shall conduct ground operations for a single Ares I/Orion mission within a threshold critical path timeline of 879 hours



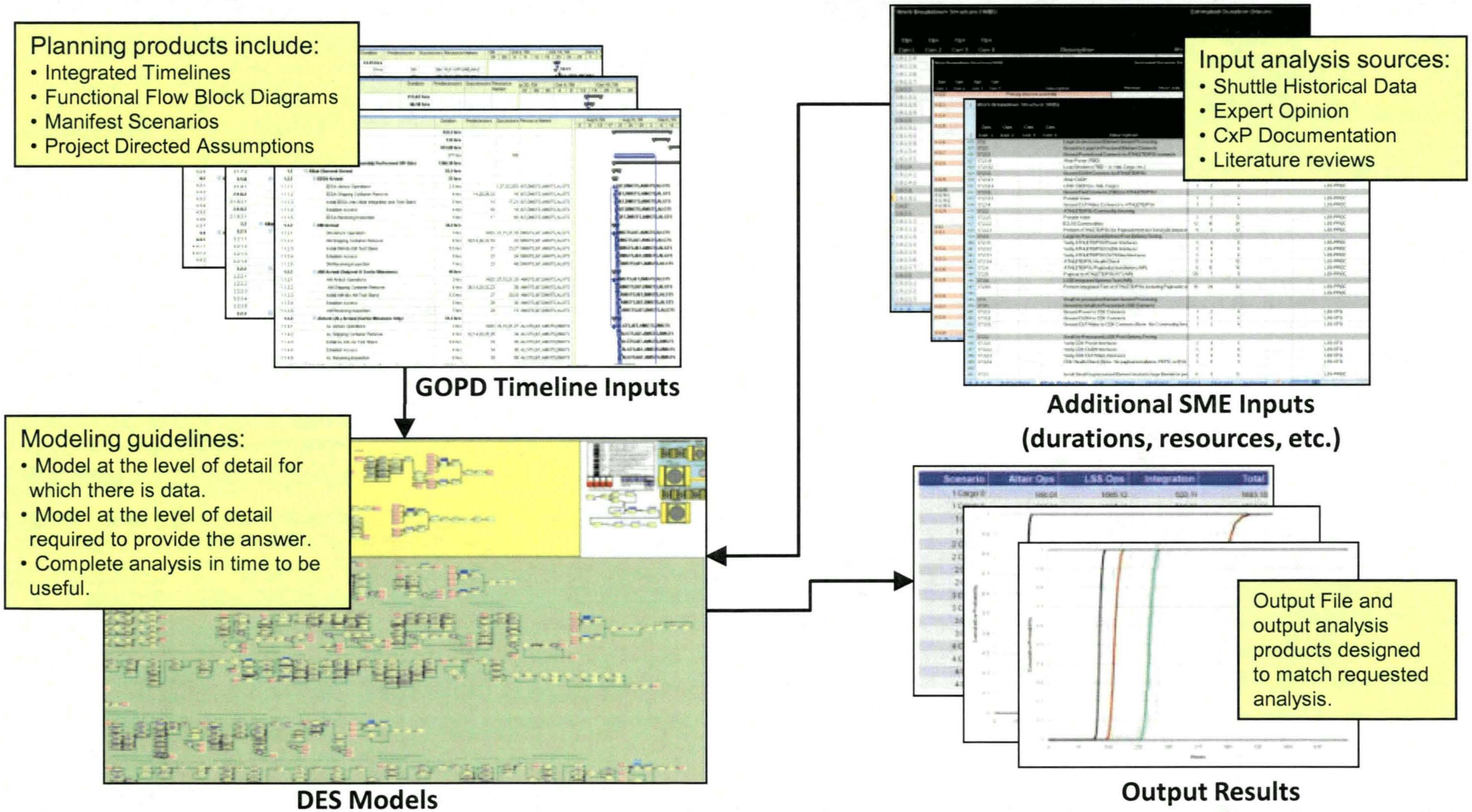


◆ Scope

- Integrated timeline represents an Ares I/Orion nominal flow during "steady state" operations including offline operations (post-AI&P) and integrated operations (VAB/ML/Pad)
  - ➢ Durations are based on single-point estimates and tracked in work-hours (no shifting)
- Significant improvements have been made by the projects to achieve the critical path requirements
  - ➢ GOTAR-01 launch-to-launch critical path duration was 920 hours
  - ➢ GOTAR-12 launch-to-launch critical path duration is 867 hours

DES Modeling - Process Overview

Discrete Event Simulation is a computer-based modeling technique for complex and dynamic systems where the state of the system changes at discrete points in time and whose inputs may include random variables.



Ground Ops DES Based Analyses

- Constellation Ground Operations Project PDR Requirements Analysis
- Maximum Flight Rate Analysis
  - Integrated Operations (VAB/ML/Pad)
  - Orion Offline Operations (MPPF)
- Confidence Level Assessments
  - Integrated Timeline (GOTAR)
  - Orion Offline Operations (MPPF)
  - Ares Offline Operations (RPSF)
- DES Demonstration at Virtual Mission Simulation
- KAMAG Transporter Study
- First Stage Surge Capacity Study
- VAB Highbay Selection Study
- 90-Minute Launch Separation Study
- Altair Ground Architecture Study
- Lunar Budget Baseline Exercise
  - Identified need to have a 2nd ML and VAB HB for the Ares V during the lunar era
- Augustine Committee & Heavy Lift Launch Vehicle (HLLV) Study
  - Provided Flight Rate Analysis for Multiple Architectures and Vision Strategies
- Probability of Meeting Planned Milestones Study
- Launch Probabilities and Distributions for PDR

Ground Operations Planning Document and Database (GOPDb)

- **GOPD Database (GOPDb) provides detailed ground operations information**
  - Tasks with High Level Work Steps
  - Hazardous Operations
  - Required Subsystems
  - Required Support Services
  - Required GSE
  - Required Personnel
  - Resource Loaded Nominal Timelines
- **GOPDb provides user-friendly data entry, review, approval and reports**
  - Task listings
  - Resource listings
  - Nominal Timelines

Source: Boeing

FIGURE 4.14-2 EXTERNAL ACCESS

Steps

1. Move/lower and secure external platforms around the CM. Verify clearance from the Outer Mold Line (OML) to the CM is acceptable.
2. Establish ground connection from platforms to facility. Verify resistance is within spec.
3. Install protective covers on the CM exterior, including windows and areas of the vehicle that are vulnerable to ground processing damage.

4.14.1.2.2 CM Establish Internal Access

Activity Type: Nominal

Description

Access to the interior of the Crew Module is established.

GS Subsystems

a. Gases, Environmental Control Subsystem (ECS)
b. Mechanical, Handling and Access – GSE

Steps

1. Prior to opening the hatch, use the Manual Pressurization and Equalization Valve (MPEV) to vent the cabin. The valve is built into the side hatch.
2. Open the crew hatch and latch it to its open position. Hatch Counter Balance Mechanism (CBM) flight design and any related Ground Support Equipment (GSE) operation is <TBR 4.14-2>.
3. Install a protective cover over the hatch.
4. Install the hatch ring cover.

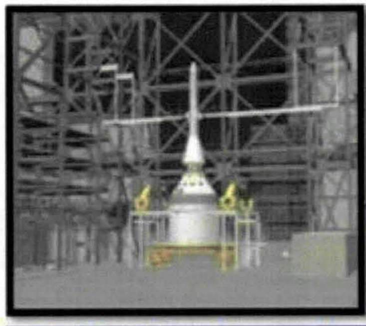
Operability Success Stories

- **Operability, in general, can be thought of as the extent to which the maximum mission objectives can be achieved at the lowest cost over the program lifecycle**

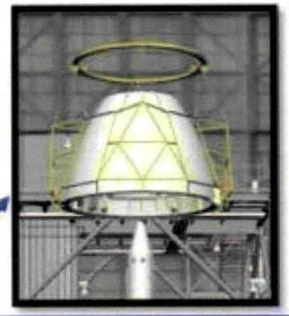
- **Often, improving operability means optimizing several competing figures of merit**

- **Operability figures of merit specific to Ground Operations include the following:**
  - Improvement of safety to personnel and/or hardware
  - Maximization of throughput or flexibility to meet dynamic manifest needs, and minimization of processing critical path
  - Minimization of facility/industrial "footprint" required to support operations
  - Maximization of capability to launch on time
  - Minimization of touch labor

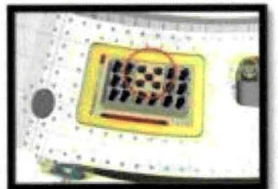
Operability Success Stories – Orion/LAS



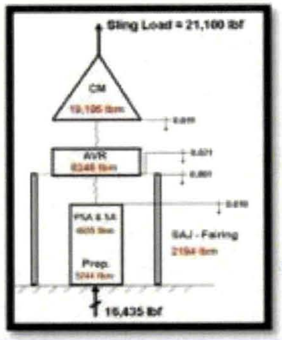
A. Orion design changed to add integrated lift capability



B. Design changed to a one Piece Ogive



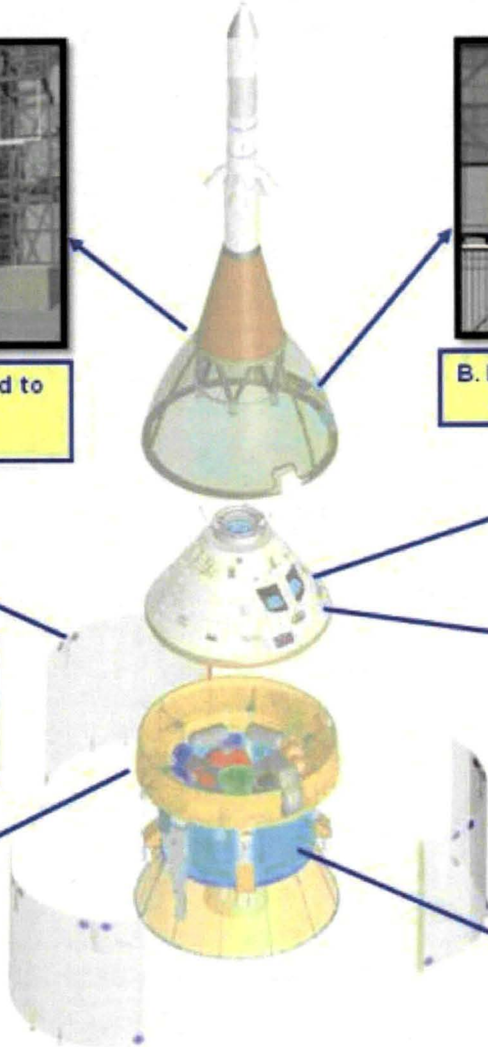
C. Elimination of full Vehicle Power-up for Post-Flight Deservicing



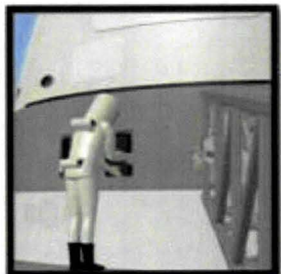
G. SM Fairing removal capability without de-integration of the CM

H. Ares/Orion SA/IU Interface

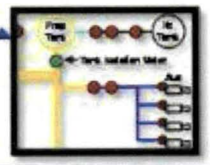
- Exterior (versus internal) mating of fasteners
- Thermal closeout with preformed material
- Alignment cues for stacking



D. Orion COPVs now meet CARD 100 day requirement without depressurizing



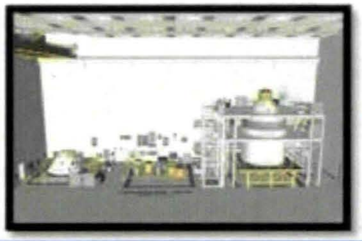
F. Relocation of the SM T-0, Pyro, and Servicing panels



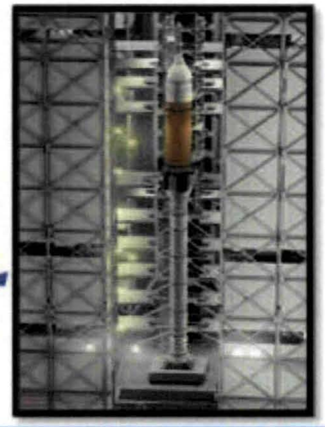
E. Orion propulsion systems optimized for offline servicing

Operability Success Stories – Ground Systems

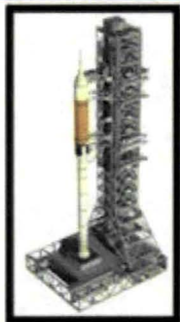
Single String Architecture



A. Multi-Payload Processing Facility (MPPF)
- Orion offline hazardous servicing, CM de-servicing and GSE storage combined in MPPF, reducing O&M costs for additional facilities



B. Vehicle Assembly Building (VAB)
- New platforms selected over modified Shuttle platforms, allowing for optimal access at desired locations
- Major facility refurbishments have rehabilitated VAB doors, siding and roof, enhancing hurricane protection and reducing O&M costs



D. Mobile Launcher (ML)
- Integrated ML concept – base, tower and all GSE – provided as consolidated system
- Vehicle Access Arms (VAA's) – Stowed on side of tower to minimize launch damage, electric drive system (no hydraulics)
- Launch Mount design provides flexibility for vehicle and processing changes
- Tilt Up Umbilical Arm protective upgrades: Safe-house; Stainless steel truss
- ML Structure utilized stainless steel cylindrical tubing, blast deck, and heat shields

E. Launch Pad 39B
- Clean pad concept maximizes flight rate of most expensive architectural feature, simplifying transition to future programs and reducing potential need for additional launch pads
- LC 39B Lightning Protection System - Provides isolated 'Faraday Cage' and compatible with any vehicle up to VAB door height (~400' vehicle)

C. Command Control and Communication (CCC)
- Consolidated Control Rooms in the LCC
- Launch Control System (LCS) - Use of the Standards Based Architecture and industrial control systems

Kaizen Improvement Event:

Recommend improvements for assembling Launch Abort System (LAS)

Include flight hardware, GSE and assembly sequence changes

The way we used to do it…

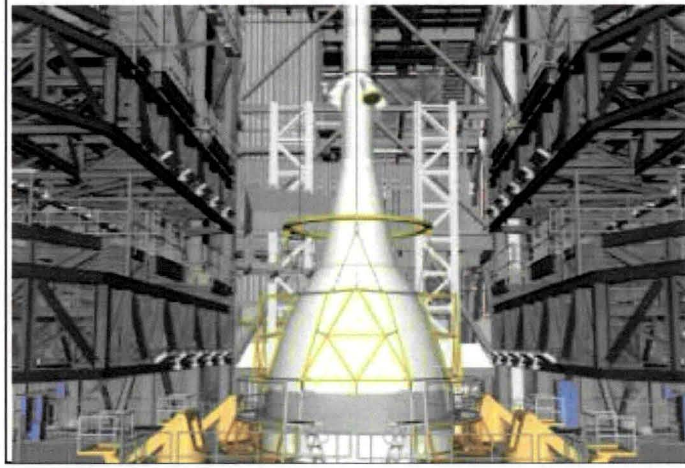
- *Assembly is time consuming, involves many fasteners, access points and TPS closeout operations.*
- *Assembly does not align with the CARD critical path timeline.*

The changes we made…

- *Eliminated rework (re-assembly)*
- *Integrated Programmatic Schedule Approach*
- *Preassembled ogive panels*

The way we plan to do it in the future

- *Further refine approach as an integrated team and optimize flow*



Sponsors: *Kelvin Manning (GOP)/Joe Voor / Bill Cummins*
Team Leader(s): *Gary Letchworth (GOP), Richard Martin (Orion)*
Facilitator: *Jill Dobson (MBB),*
Team Members: *See attached list*

Category	Before	After	Improvement
"Full Future State"			
Fastener count (~56 lb mass increase)	693	365	328
GOTAR Critical Path*	113.5 hr	66.5 hr	47 hr
VAB Timeline	211.5 hr	89 hr	122.5 hr (incl parallel ops)
- Short Stack Stacking	50.5 hr	34.5 hr	16 hr
- LAS Stacking	47 hr	32 hr	15 hr
- Ogive Installation	113 hr	41 hr	72 hr

*** Segment (5) – Start of Orion/LAS Stacking through Ready for Integrated Test and Vehicle Closeout Preparations**

Lean Event Example – Orion Delivery Schedules

- **Orion 1 & 2 Delivery Lean Event Findings**
  - Identified Project-to-Project disconnects for future planning
    - If ground flow time significantly increases, battery life may become an issue. Continue looking at all limited life items to meet 100 day stacked requirement and related contingencies
    - Inconsistent application of schedule margin management across Projects (Generic overarching Learning curve by GO vs. low level task specific by Orion)
    - Program Software delivery disconnects for Orion Offline operations (3 months late)
  - Identified ideas of improvement for future planning
    - Cooling of COPVs to reduce servicing times
    - Servicing Hydrazine (CM) and MMH (SM) in parallel
    - Ammonia in parallel
    - Antenna testing location synergies - Orion S-band VAB testing (CM Antennas) requirements definition immature
    - Pathfinder activities to accelerate learning
    - Participation in pre-GO activities to accelerate learning
    - Move MEIT earlier and spread to pre-GO where possible
    - Partial or full gas servicing pre-GO where possible
    - Hazardous ops shifting from 2 to 3 shifts

Mockups

- **Interface between spacecraft and CAA**
  - Proof of concept considerations: hatch size and orientation, fall protection, access to service panels, purge locations, hazardous environment mitigation, oxygen deficiency
- **Nominal Crew Ingress/Egress Considerations**
  - GSE to Spacecraft Interface Points/Location
    - Attached points, handle locations, fall protection, handrails
  - Crew Seat Design
    - Closeout crew assistance , seat installation/removal
  - ECS Duct Location
- **Emergency Crew Egress**
  - Seat Orientation in relation to Hatch
  - Emergency Response Crew GSE
    - Diving Board, escape harness
  - Rescue Gear
    - Breathing Air Packs, other tools

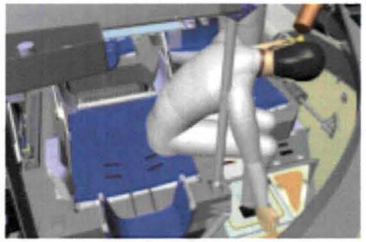
Human Factors Analysis - Process

- **Timeline activities were analyzed for hardware human interactions affecting the human performance during assembly, maintenance, inspection of Orion**
- **Federal Aviation Administration (FAA) Human Factors Design Standards (HFDS) were used to identify and resolve Human factors issues.**
- **The team modified a Human Factors Engineering Analysis (HFEA) tool developed by the KSC Engineering Directorate by re-arranging the analysis spreadsheet to show a timeline of events. For each of the events, 5 areas in the tool were addressed.:**
  - Human interface, Issue, Processing Phase, Risk Analysis and Recommendations
- **Example 1 – moving the short stack pallet into and out of servicing bay.**
  - Alignment of pallet into the servicing bay was considered an issue that required further evaluation.
  - A recommendation was provided to the design team to install guide rails on floor.
- **Example #2 – connecting, disconnecting, and stowing hoses from the transporter.**
  - The weight and flexibility of the hoses was considered an issue.
  - An action was taken by the team to assure the hoses can be lifted by the technicians.
  - It was recommended to change the design of the hoses to be in sections to reduce weight to below these human factors requirements.

Reference: Human Factors Operability Timeline Analysis to Improve Orion Processing Flow, Schlierf & Stambolian, 9/27/10

Human Factors Analysis - Lessons

- **The NASA Constellation program level human factors requirements document HSIR greatly promoted better human factors Systems Engineering and Integration.**
  - This improved the integration between ground systems, crewed vehicle designs for ground processing.
- **Early collaboration and planning between the flight and ground hardware designers for human factors operability engineering analysis (HFEA) is necessary.**
- **Timeline analysis is great way to analyze and improve the design of ground and flight hardware interfaces for ground processing of the ground equipment, and the flight and ground hardware interface.**
- **Employ qualified human factors person/s on team from the beginning of the Project.**
  - Human factors engineers should perform the human factors assessments as embedded members of the design teams.



Reference: *Human Factors Operability Timeline Analysis to Improve Orion Processing Flow,* Schlierf & Stambolian, 9/27/10